Glass Resistive Plate Chambers for Muography IMaging of volcanoes

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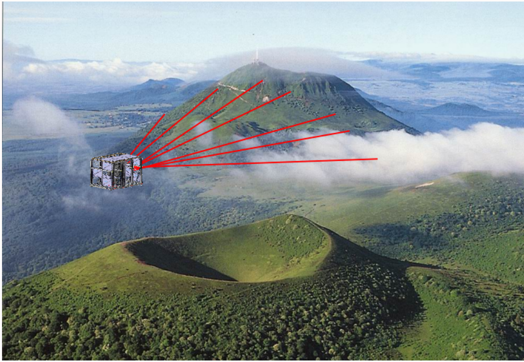
on behalf of the TOMUVOL collaboration

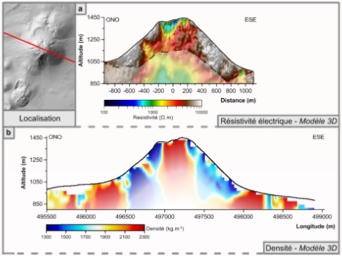
Instrumentation Days on gaseous detectors 2016
12-13 October 2016, LPC

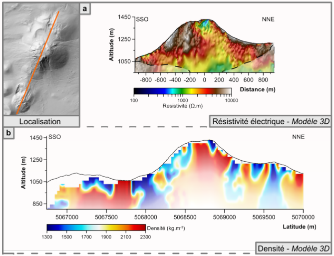


Outline

Imaging volcanoes

- Goals: volcanic hazard mitigation, prediction of their future behaviour from internal structure and past activity
- Several methods are usually used to study the inner structure of volcanoes:
  - electrical resistivity tomography → (fluids, alteration, nature of rocks)
  - gravimetry → density
  - magnetization → local variation of magnetic field induced by rocks
  - seismic tomographies → elasticity and seismic waves velocity
- Difficult to access large depth, complex, ill-posed inverse problem and usually on the volcano itself (resistivity and gravimetry)

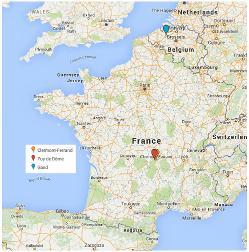


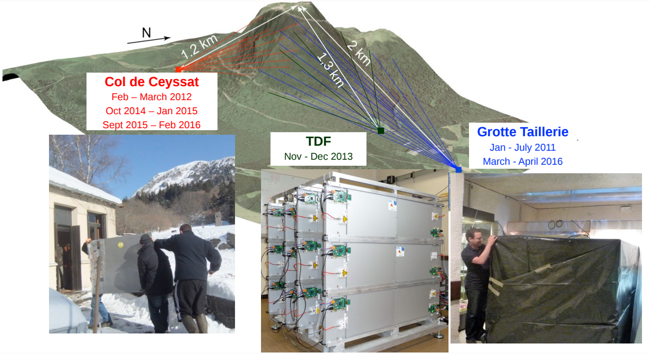


Ref: Portal et al., 2015, JVGR, submitted

Tomuvol experiment

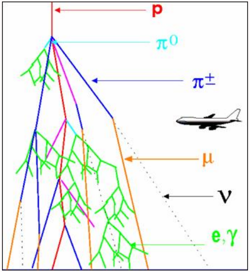
- Goal: Proof of principle for imaging volcanoes with atmospheric muons (muography) using the Puy de Dôme volcano.
- Collaboration: LPC, LMV, IPNL, ESGT
- Steps
  - 2011-2012: Preliminary campaigns with CALICE GRPCs
  - 2012: Building and commissionning a dedicated detector
  - 2013-2016: Data-taking campaigns with the Tomuvol chambers on Puy de Dôme



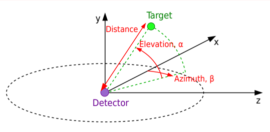


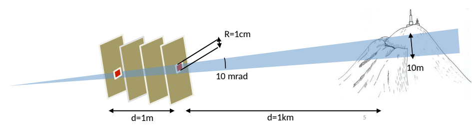
Muography

- Principle same as for radiography: a radiation passes through a target and we build a 2D image from its transmittance
- As target is huge (volcano) $\rightarrow$ use atmospheric muons
  - Cross kms before decaying
  - Large energy spectrum: 100 MeV $\rightarrow$ PeV
  - Simple trackers and no direct measurement of incoming flux
- Advantages:
  - Complementary to other geophysical methods
  - Remote imaging ($\simeq$ 1 km)
  - Good intrinsic spatial resolution ($\simeq$ 10 m)
  - Well-defined 2D inverse problem (measurement of average density along line of sight)
- But (very) high energy muons are rare



Principle of the analysis



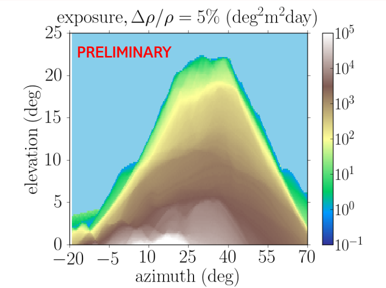


$$\mathcal{T}_\rho(\alpha, r(\alpha,\beta)) = \frac{\phi(\alpha, r(\alpha,\beta))}{\phi_0(\alpha)} \quad \text{with} \quad \int \rho(\alpha,\beta) dr = \mathcal{F}(\mathcal{T}_\rho)$$

ρ: density to be determined through integrated density over a direction where $\mathcal{F}$ is a bijection (unique solution)

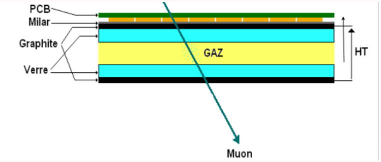
$$\phi(\alpha,\beta) = \frac{N(\alpha,\beta)}{S_{eff}(\alpha,\beta)\Delta T \Delta\Omega} \quad \textit{with} \quad S_{eff}(\alpha,\beta) = S_{det}\varepsilon_{geom}\varepsilon_{illum}\varepsilon_{det}$$

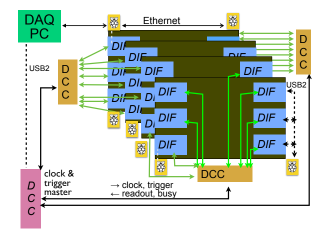
- If high resolution wanted, high exposure needed (exposure = $S_{eff} \times \Delta T \Delta\Omega$)
- Possible compromise between density resolution and angular resolution depending on physics goal
- Ex: exposure to get an uncertainty of 5 % on the measure of the density



Tomuvol detector

- 4 layers of 6 GRPCs made at IPNL, following CALICE SDHCAL GRPCs
  - 1 layer $\sim$ 1 m^2
  - readout cells of 1 cm^2 ($\sim$ 40000 cells)
  - 1.2 mm gap
  - Gas: 93.0% $C_2H_2F_4$, 5.5% C_4H_{10} and 1.5% SF_6
  - Nominal HV: $\sim$ 7.5 kV @ P = 1.013 hPa and T = 20 °C
- Electronics:
  - synchronous at 5 MHz, auto-triggered
  - very front end: semi-digital Hardroc2 ASICs from Omega (Palaiseau), 64 channels, low power consumption (3.5 mW/channel), 3 thresholds
  - front end: DIF board from LAPP (Annecy)
- Slow control:
  - PLC (gas, HV, LV, environmental conditions)
  - remotely monitored from web interface



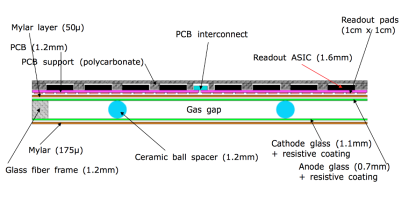


Zoom on GRPCs

1st try with GRPCs from CALICE collaboration for SDHCAL before customization

CALICE SDHCAL GRPCs

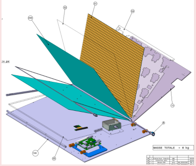
- 1 m^2 chambers
- 6 PCB of 50×33 cm^2
- Float glass: 0.7 and 1.1 mm
- Independent gas circuit
- 1 DIF for 2 PCB
- Iron cassette

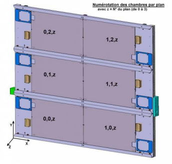


Ref: Beaulieu et al., JINST 10 (2015) 10, P10039

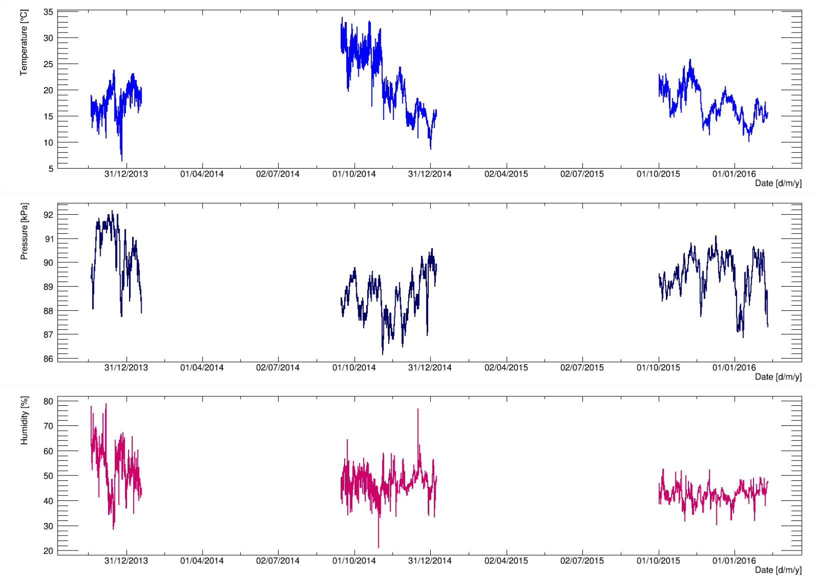
TOMUVOL GRPCs

- 50×33 cm^2 chambers following the existing PCB geometry
- 1 PCB of 50×33 cm^2 per chamber
- Float glass: 2×1.1 mm
- Chambers chained by 3 for gas circulation
- 1 DIF for each PCB
- Aluminium cassette

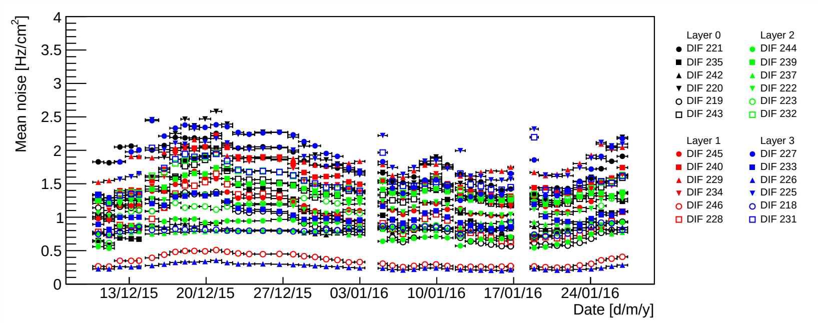


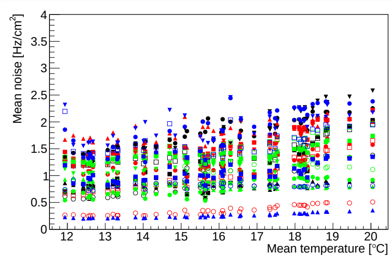


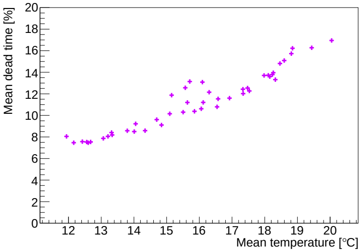
Atmospheric conditions



CDC 2015-2016: noise and dead time (1)

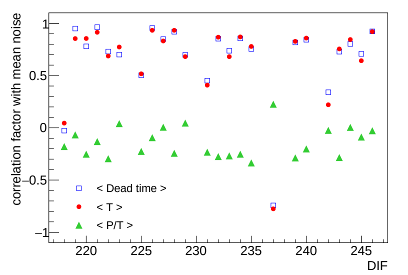






CDC 2015-2016: noise and dead time (2)

DAQ is limited by the USB protocol used for reading the FE boards → important dead time when the noise is increasing



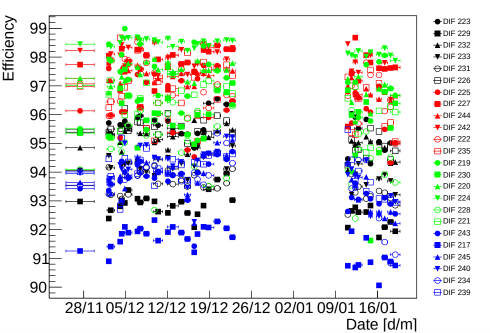
HV corrected for P/T:

$$HV_{eff} = HV \times f_{corr} \qquad \text{with} \qquad f_{corr} = \frac{P}{P_{ref}} \frac{T_{ref}}{T} \qquad (P_{ref} = 1.013\,\text{hPa}, T_{ref} = 293.15\,\text{K})$$

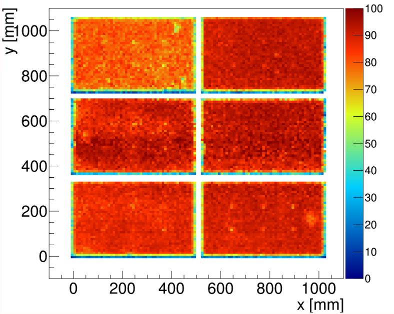
→ still a correlation with temperature.

Efficiency

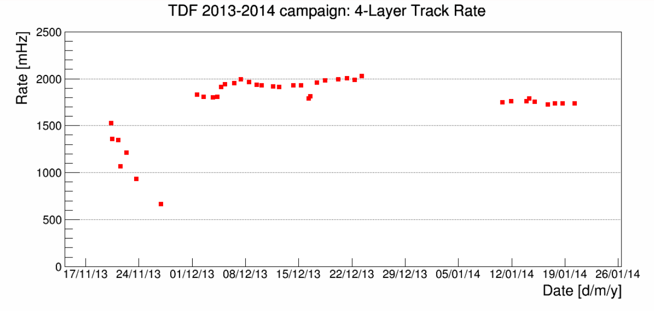
Stability of efficiency over the TDF campaign in 2013

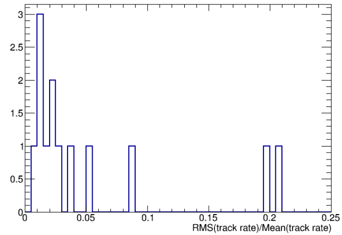


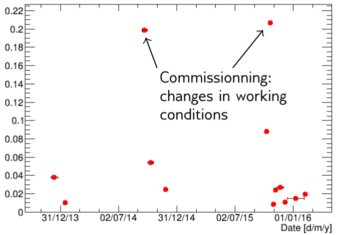
Efficiency in layer 0 during the CDC campaign in 2015 - 2016



Rate stability

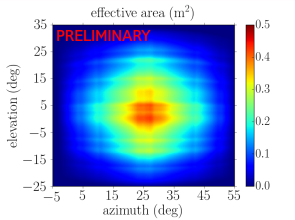


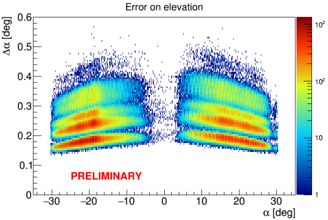


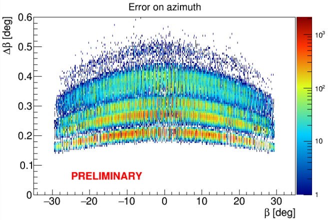


Final analysis

- Alignment of the detector (February 2016)
- Very preliminary results on the CDC 2015-2016 campaign

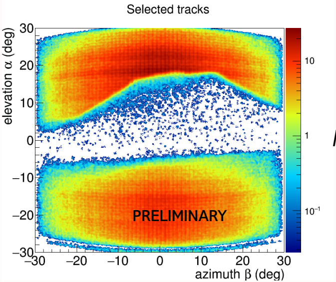




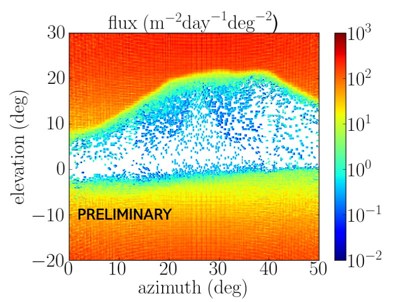


Data: CDC 2015-16

Using detector performances



$N(\alpha,\beta) \rightarrow \phi(\alpha,\beta)$



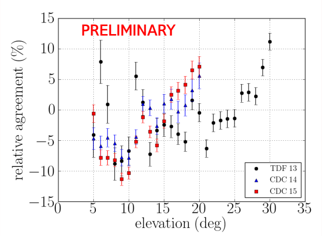
Using $\phi(\alpha,\beta) = \dfrac{N(\alpha,\beta)}{S_{eff}(\alpha,\beta)\Delta T \Delta\Omega}$ *with* $S_{eff}(\alpha,\beta) = S_{det}\varepsilon_{geom}\varepsilon_{illum}\varepsilon_{det}$

Flux through the Puy de Dôme

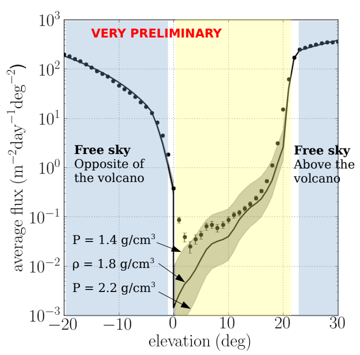
Model of the muon flux

- Homemade Monte-Carlo
- Using Chirkin's differential spectrum of atmospheric muons (arxiv:hep-ph/0407078)

For the moment, systematic uncertainty estimated from comparison between data and model in the free sky



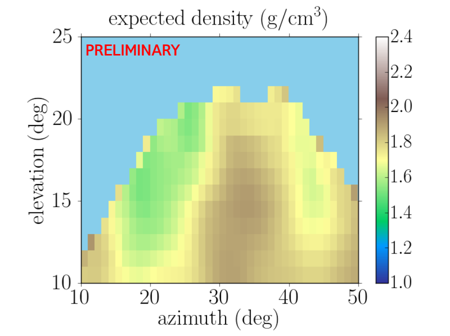
$$rel.\ agreement = 100 \times \left(\frac{data}{pred} - 1\right)$$



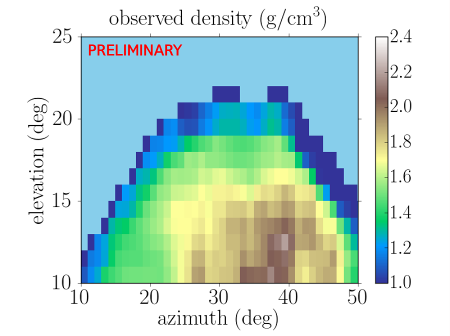
Flux integrated over β

Muon data vs gravimetric model

Gravimetric model



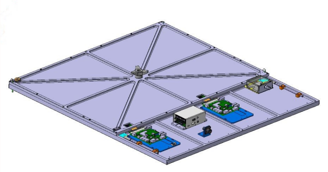
Muon data



- The muon data are obviously contaminated close to the border, e.g. uncertainties on the muon direction, background leakage flux of low energy particles.
- There is a qualitative agreement on a denser core below 15° of elevation, but not for the somital area.

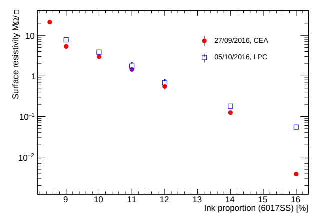
R&D for building new chambers

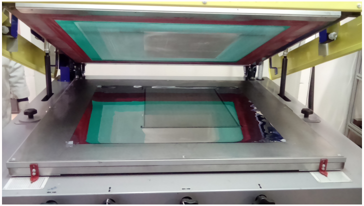
- Goals
  - Improving spatial and temporal resolution by a factor 10 $\rightarrow$ multi-gap GRPC
  - Reducing cost, electrical consumption and complexity $\rightarrow$ readout by strips
  - Reducing gas consumption
- Glass and coated electrodes characterization (serigraphy with CEA-Saclay, AIDA 2020)
- New scheme for gas circulation and new gas inlets/outlets
- Gas tightness



Serigraphy and resistivity measurements

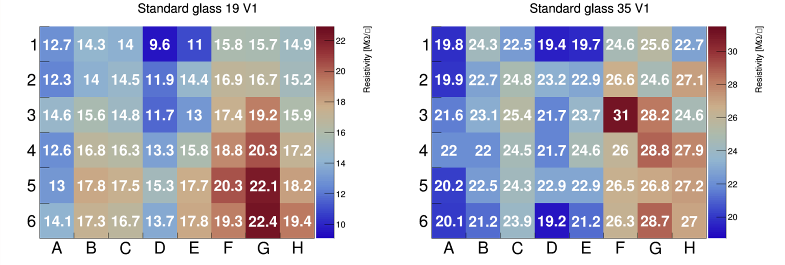
- Serigraphy with CEA-Saclay, AIDA 2020
- Various mixing of painting tested (2 components, variation in proportion)
- Measurement of surface resistivity of the coating





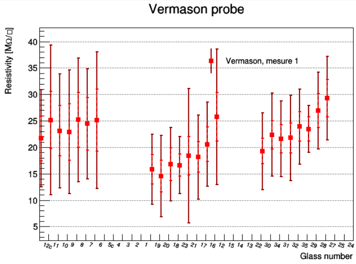
Resistivity measurements

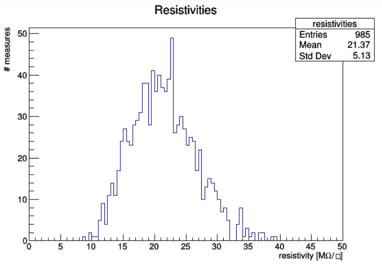
Example: glasses 67 $\times$ 51 cm^2



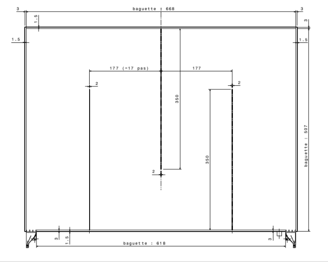
Summary of resistivity measurements

Summary for glasses 67 $\times$ 51 cm^2:

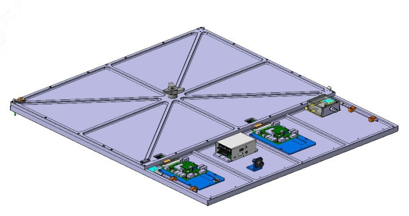


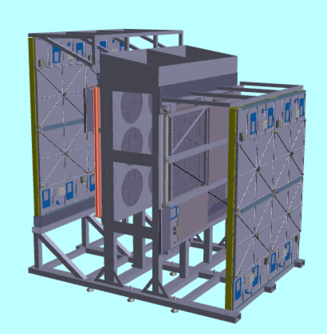


Construction of new chambers



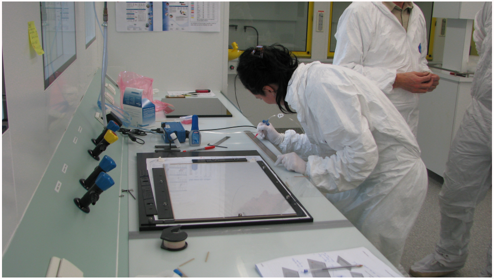
- New gas circulation, including new inlets
- Twice the size
- New cassette



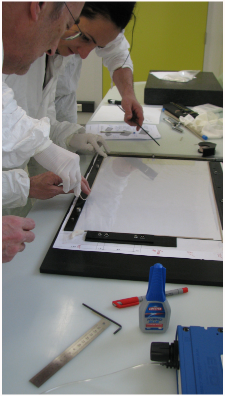


Pasting the 1st glass

Gluing of the external sticks on the glass receiving the HV

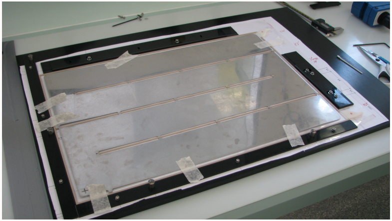


Gluing sticks.



Pasting the stick on the glass (corresponding to HV).

Spacer pasting

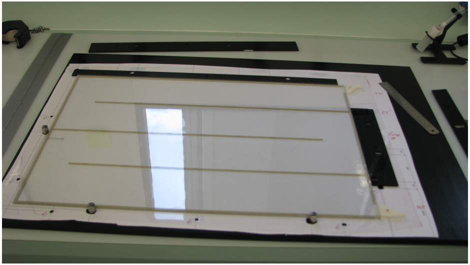


Mask for spacers and spacers.

Pressing :-)

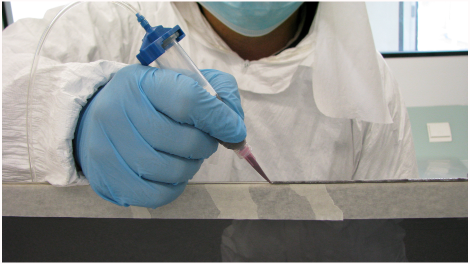
2nd glass pasting

Gluing of sticks and spacers already pasted.



A chamber!

Gas tightness



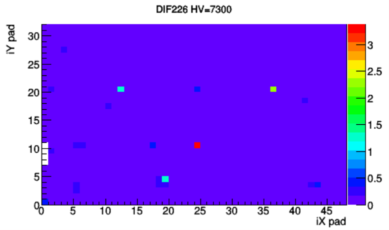
Gluing between the glasses.

Chambers drying.

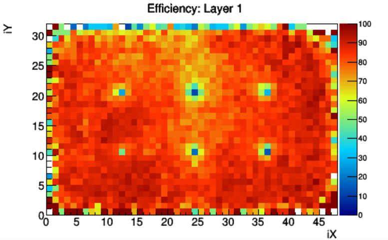
First tests of chambers

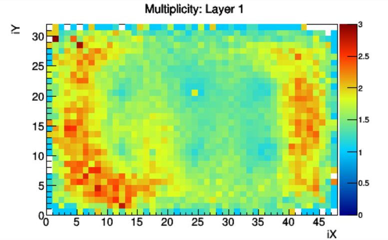
Test done on small chambers prototypes

- Noise
- Efficiency
- Multiplicity



Noise (Hz/cm^2)





Conclusion

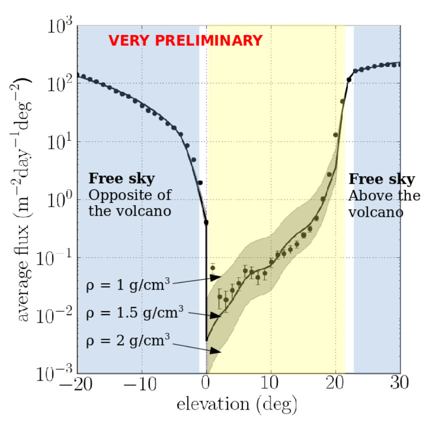
- RPCs are very good choice for imaging large volcanoes
- Sensible to atmospheric conditions → corrections
- Improvements foreseen to optimize (Multi-gap)GRPC to our application, low gas and electrical consumption, portability, autonomy in energy, etc.

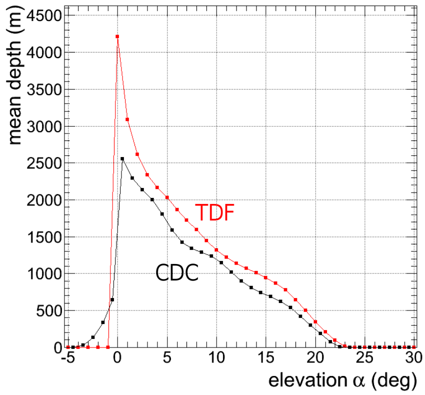
Thank you for your attention

References

- Inner structure of the Puy de Dôme volcano: cross-comparison of geophysical models (ERT, gravimetry, muon immaging), A. Portal et al, Geosci. Instrum. Method. Data Syst., 2, 47-54, 2013
- Towards a muon radiography of the Puy de Dôme, C. Cârloganu et al., Geosci. Instrum. Method. Data Syst., 2, 55-60, 2013
- Joint measurement of the atmospheric muon flux through the Puy de Dôme volcano with plastic scintillators and Resistive Plate Chambers detectors, F. Ambrosino et al., J. Geophys. Res. Solid Earth, 120, doi:10.1002/2015JB011969, 2015 (MU-RAY and TOMUVOL collaborations)
- RPC application in muography and specific developments, E. Le Menedeu (for the Tomuvol Collaboration), 2016 JINST 11 C06009, proceeding from RPC2016

Puy de Dôme thickness





Estimation of α and β